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TRMM Radar

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Abstract

Results of conceptual design study and performances of developed key devices of BBM of the TRMM radar are presented. The radar , operating at 13.8 GHz and designed to meet TRMM mission objectives, has the minimum measurable rain rate of 0.5 mm/h with a range resolution of 250 m, a horizontal resolution of about 4 km, and a swath width of 220 km. A 128-element active phased array system is adopted to achieve a contiguous scanning within the swath. The basic characteristics of BBM were confirmed by experiments. The development of EM has started with the cooperation of NASDA and CRL.

1. Introduction

TRMM(Tropical Rainfall Measuring Mission) is a joint space program of the USA and Japan(Ref. 1) to measure rainfall of tropics where about 60% of the global rainfall is concentrated. The feasibility study(Phase A) of TRMM was performed successfully under the joint efforts of the USA and Japan from January 1987 to March 1988 and TRMM project was evaluated to be feasible. Phase B activities of TRMM were completed both in USA and Japan, and both countries are doing Phase C/D activities now. TRMM will adopt a circular orbit with the altitude of 350 km and the inclination of 35° . TRMM will be launched in August 1997 by the Japanese H-II rocket.

The goals of TRMM are, (1)to advance the understanding of the global energy and water cycle by means of providing distributions of tropical rainfall, (2)to understand the mechanism through which the tropical rainfall affects the global circulation, and to improve the global circulation model, and (3)to evaluate satellite system for rainfall measurement. The primary mission product of TRMM is the monthly averaged rainfall over $5° \times 5°$ grid boxes between the latitude of 37° N and 37° S with an accuracy of about 10% over three years. TRMM is required to understand tropical rain processes that play a key role in climate changes, particularly El Nino and Southern Oscillation. TRMM will contribute to international global change programs such as GEWEX.

2. Conceptual Design Study of TRMM Precipitation Radar

TRMM is the first space mission dedicated to measurements of tropical rainfall with the first precipitation radar in space. Communications Research Laboratory (CRL)performed a conceptual design study of TRMM precipitation radar in the feasibility study of TRMM in cooperation with NASA/GSFC (Ref. 2,3). The mission requirements for the TRMM precipitation radar basically specified by NASA are summarized in Table 1. These requirements were used as the guideline for the design of TRMM precipitation radar.

In the precipitation model, the rain is assumed to be uniform and extends to a height of 5 km. The thickness of the bright band or the melting layer is 0.5 km and the attenuation coefficient in the melting layer is assumed to be twice as large as that of rain below the melting layer. The following relations between the effective Z-factor $Ze(mm^6/m^3)$, attenuation coefficient A(dB/km) and rain rate R(mm/h) for 13.8 GHz are assumed: $Ze = 372.4 R^{1.54}$ (Ref. 4) and $A = 0.032R^{1.124}$ (Ref. 5).

In the TRMM precipitation radar, radar antenna beam is required to scan a swath width of 220 km in the cross track direction every 0.6 seconds in order to observe a raining area without any gaps between scanning lines which are perpendicular to the moving direction of the satellite. Therefore, high speed electric scanning becomes essential.

Figure 1 shows the block diagram of the TRMM radar(Ref. 6). Active array radar is selected as a reliable candidate for the TRMM precipitation radar after trade off studies in the feasibility study. The system is reliable because it is still operational even if some parts of transmitters or receivers are damaged. The total system loss becomes small because transmission lines between the antenna and transmitter/receiver are short and loss of phase shifter can be compensated by the SSPA(Solid State Power Amplifiers) and LNA(Low Noise Amplifier).

Main system parameters estimated in the feasibility study are shown in Table 2. The attained horizontal resolution is 4.3 km at nadir and the range resolution is 250 m. The swath width is 220 km. The required number of independent samples of 64 is achieved by the frequency agility technique which uses dual frequency separated 6 MHz. Dual frequency pulse will be transmitted mutually in the same pulse repetition period keeping a pulse repetition period long enough to insure the sufficient time for the data acquisition., The minimum detectable rain rate at the rain top is 0.5 mm/h and the measurable rain rate at the rain bottom is between 0.5 mm/h and 52 mm/h, with a signal to noise ratio of 0 dB for a single echo. If we use the attenuation data of the sea surface echo by rain, we can observe the average rain rate as large as 80 mm/h with a signal to noise ratio of 0 dB for a single echo.

3. Development of Key Devices of the Bread Board Model of the TRMM Precipitation Radar

CRL has developed key devices of the Bread Board Model of the TRMM precipitation radar since 1988(Ref. 7). These key devices are (1) slotted waveguide antenna elements, (2) 5-bit PIN diode phase shifters, (3) SSPAs and (4) LNAs. Integration of these components to form an 8-element Bread Board Model of the TRMM precipitation radar was also made. We developed 8-element slotted waveguide array antenna. Major required characteristics of the antenna are (1) the low sidelobe level to suppress the surface clutter, (2) the wide band width for the frequency agility, and (3)the high speed electric scanning with scan angle of ±17 degrees. We adopted the non-resonance type(wide band width)slotted wave guide antenna. The separation between slots cut on the narrow wall of the rectangular waveguide is 13.65 mm. Slot conductance is designed to attain the Taylor amplitude distribution(sidelobe = -35 dB, parameter n = 6) along the waveguide axis. Figure 2 shows outside appearance of the developed 8-element slotted waveguide array antenna part of the Bread Board Model of TRMM precipitation radar. The antenna length is 2.2 m. Measured antenna

Table 1. Mission Requirements

Frequency	13.8 GHz
Satellite altitude	350 km
Scan angle	±17.0 degrees
Swath width	220 km
Range resolution	250 m
Horizontal resolution	around 4 km at nadir
Minimum measurable rainfall rate	0.5 mm/h at storm top
Observation range	
Nadir	15 km + 5 km
Scan angle: θ	15 km/cosθ
Number of independent samples	64
Antenna sidelobe level	around -30 dB

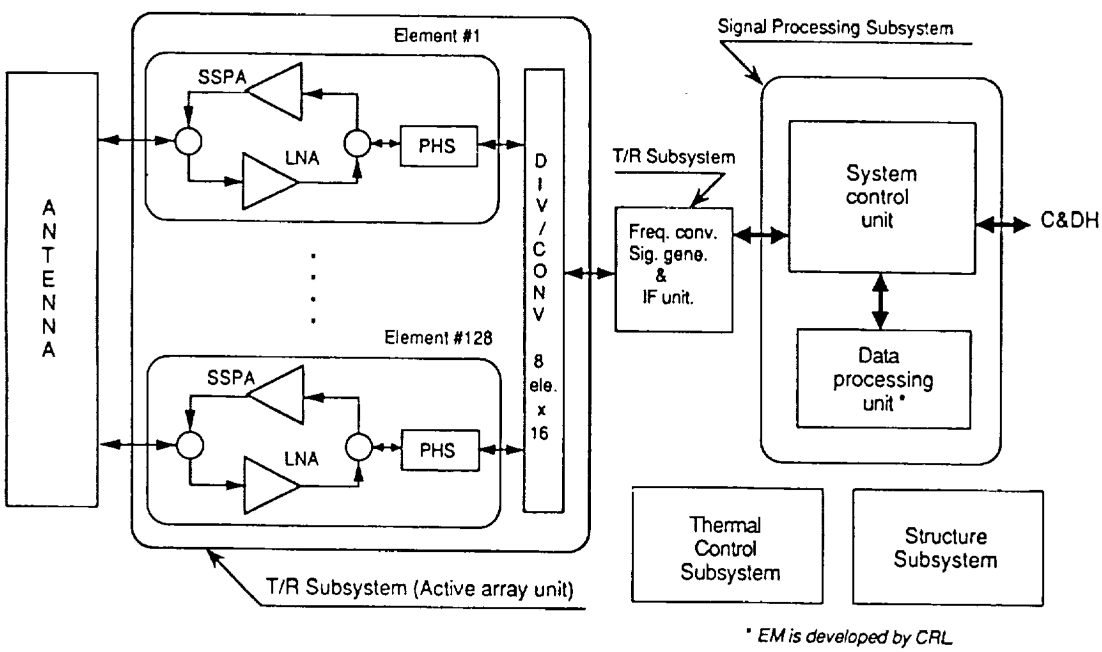

Fig. 1 Block diagram of TRMM radar

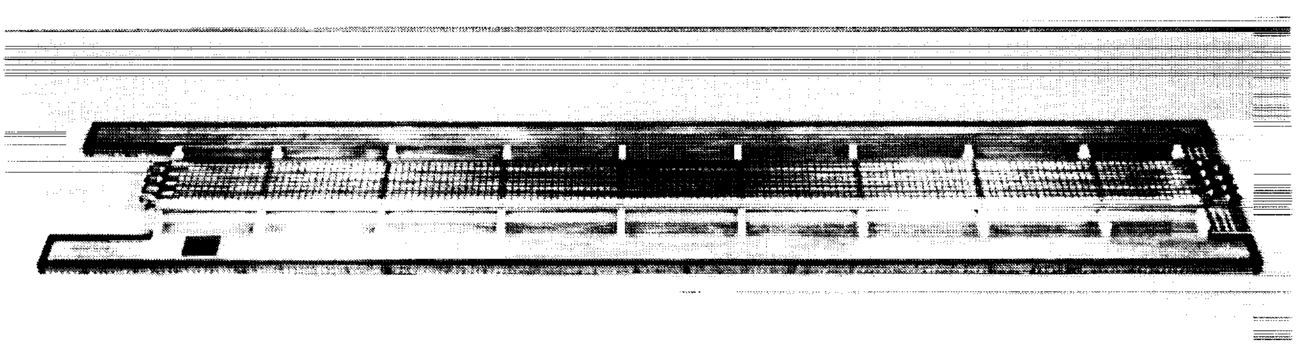

Fig. 2 Outside appearance of the 8-element slotted wave guide antenna part of the Bread Board Model of TRMM precipitation radar

radiation pattern in the plane of the wave guide axis of an 8-element slotted wave guide array antenna at 13.8 GHz is shown in Fig. 3 The half power beam width of 0.7° is attained. The peak sidelobe level about -30 dB is attained except for the shoulder level of -28 dB. The wide angle sidelobe level less than -35 dB is also attained. The antenna beam tilts about 4° from the direction normal to the slotted waveguide wall.

We developed PIN diode 5 bit phase shifter at 13.8 GHz. In the PIN diode 5 bit phase shifter, 11.25°, 22.5°, 45° and 90° bits are of loaded line type and 180° bit is of hybrid coupler type. We attained at the worst case between -10°C and +40°C, insertion loss values of 4-5 dB for the variation of the phase values. Phase errors about - 5°~ + 2° and amplitude errors less than 0.9 dB_{p-p} are attained. As the phase and amplitude errors and variation of the insertion loss are directly related to the characteristics of phased array antenna, more detailed examination and evaluation of the phase shifter will be performed for the Engineering Model. Although values of the insertion loss are larger than those of the ferrite phase shifter, these loss values can be compensated by the SSPA and LNA. The mass of the developed phase shifter is about 150 g.

In order to satisfy the peak transmitted power shown in Table 2, the output power of 10 W around the central part of the array is required. By using multi-stage GaAs FET amplifiers, output power of 10 W and an efficiency of more than 15 % is developed. In order to reduce the power consumption, the efficiency of SSPA itself, of the power supply and of the guard time margin for the pulsed operation must be considered. The output power variation is 0.2 dBp-p and the phase variation of the each SSPA is as large as 30° for the temperature variation between -10° C and +40° C. However, variation of the phase difference of 2 SSPAs whose phase difference is set to be equal at room temperature is less than $6°_{p-p}$ for the temperature variation between -10° C and +40° C, because the temperature dependence of the phase variation of 2 SSPAs is almost equal. The efficiency of the SSPA itself will be improved as large as 25% in the development phase of the Engineering Model. The mass of the developed SSPA is about 400 g.

LNA is composed of the multi-stage MIC amplifiers using the HEMT(High Electron Mobility Transistor). Good characteristics with gain of 30 dB and noise figure of 1.8 dB are attained. Variation of the phase difference of 2 LNAs whose phase difference is set to be equal at room temperature is less than $3°_{p-p}$ for the temperature variation between -10° C and +40° C, because the temperature dependence of the phase variation of 2 LNAs is almost equal. It is important to attain the temperature stability of the phase of each SSPA and LNA, and also to keep uniform the temperature of the whole radar system in order to attain the stable antenna radiation pattern.

Integration of PIN diode phase shifters, LNAs, phase adjusters and a divider/combiner is made to compose the 8-element transmitter and receiver part of the Bread Board Model of TRMM precipitation radar and the appearance is shown in Fig.4. The basic electric antenna beam scanning function by the switching of the 5-bit digital phase shifter was confirmed. The preliminary measurements of both the transmitting and receiving pattern of the 8-element active array antenna were also made to show good electric performances.

4. CONCLUDING REMARKS

Development of the Engineering Model of the radar has started with the cooperation of National Space Development Agency of Japan(NASDA) and the CRL. The Proto-Flight Model of the radar will be developed by NASDA, aiming at the launch of TRMM in August 1997 through joint efforts of USA and Japan. TRMM is

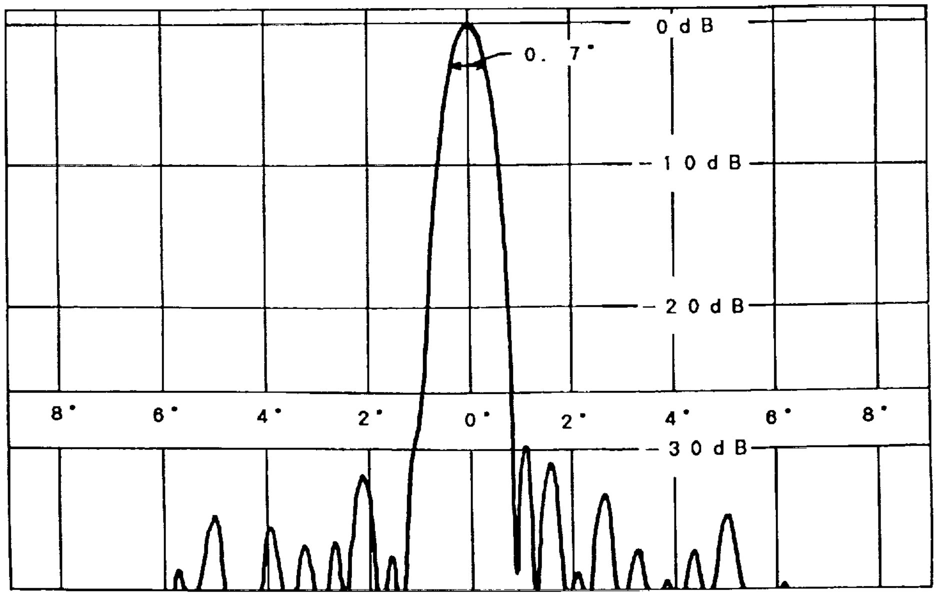

Fig. 3 Radiation pattern of a slotted waveguide array antenna element

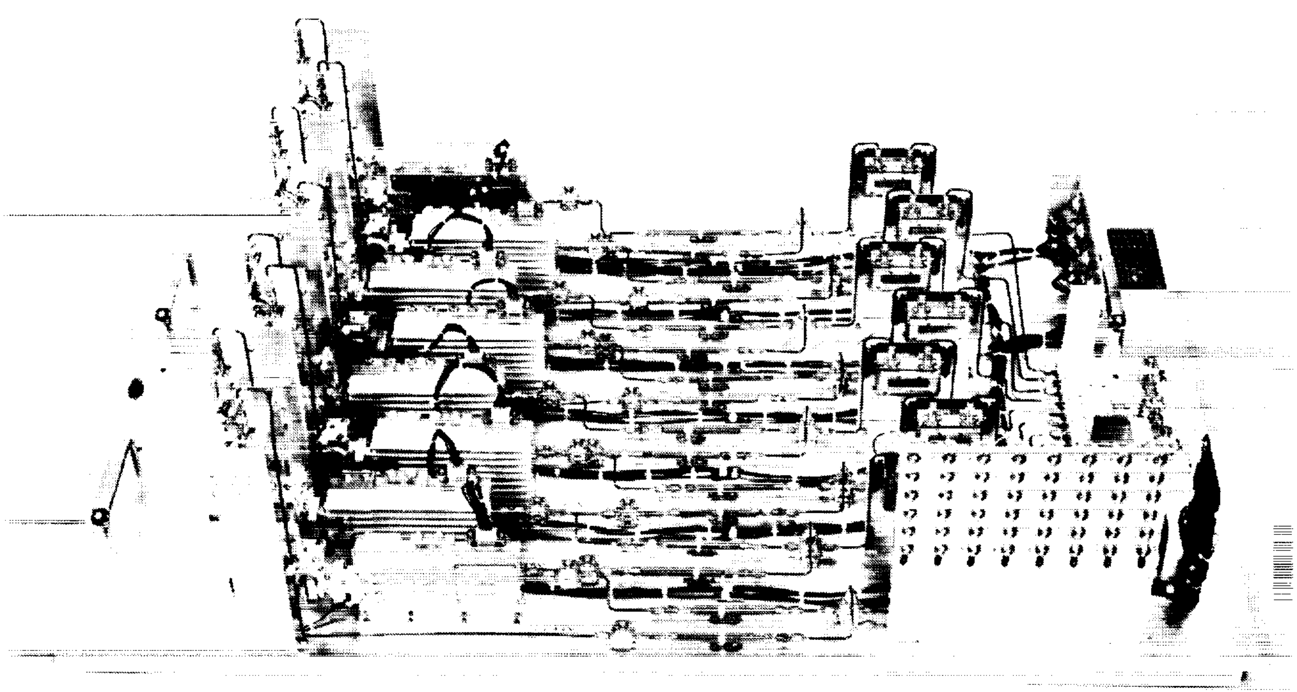

Fig. 4 Outside appearance of the 8-element transmitter and receiver part of the Bread Board Model of TRMM

Table 2. Main System Parameters of TRMM Precipitation Radar (estimated in the feasibility study)

Frequency	13.8 GHz
Antenna	
Type	Slotted waveguide array(128 elements)
Gain	47.7 dB
Beam width	0.71 × 0.71 degrees
Aperture	2.2 m × 2.2 m
Sidelobe level	around -30 dB
Scan angle	±17.0 degrees
Transmitter	
Type	SSPA(× 128)
Peak power	577.8 W
Pulse width	1.67μs × 2ch
PRF(#1)	2778 Hz
Receiver	
Noise figure	2.3 dB
IF frequency	156 MHz, 162MHz
Band width	0.78 MHz × 2ch
Characteristics	logarithmic
Dynamic range	more than 70 dB
Linearity	less than ± 0.5 dB
S_{min}	-112.8 dBm
Others	
Required S/N(#2)	0 dB for single echo
Total system loss	2.0 dB
Filter weighting loss	1.5 dB
Number of independent samples(#3)	64(32 × 2)
Data rate	85 kbps
Power consumption	224 W
Mass(#4)	347 kg

(#1) Fixed PRF; Frequency agility technique (e.g. 13.796 GHz and 13.802 GHz) is applied.
(#2) 0.5 mm/h at storm top.
(#3) Frequency agility technique is applied.
(#4) Without margin

expected to improve the understanding of global atmospheric mechanism and water cycle, which is essential for human life.

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